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What is Life?

Assembling and Understanding the Building Blocks

In an era when NASA is spending billions to examine Mars and possibly the moons of Jupiter in a search for life, seemly philosophical questions as 'How simple can life be?' and 'Can we recognize it if we see it?' become practical questions. Steen Rasmussen of EES division is currently heading an international team of collaborators working to address such questions.

This research is funded by the Center for Space Science and Exploration (in alignment with NASA's emerging Astrobiology program), the US Air Force, and the European Commission's Future and Emerging Technologies 6th Framework.

Life is notoriously difficult to define. "If life is something that can harvest resources from the environment, evolve, and reproduce itself, what do you say about a mule, which cannot reproduce?" said Rasmussen. However there is consensus in the research community that a self-replicating and evolving molecular system, that has a metabolism and genes kept together by a container, satisfies the definition of a minimal life form.

"Our team has made two recent contributions to this research area. We have redefined what a container is, and we have discovered a new way to couple the genes, the metabolism, and the container," Rasmussen noted and he continues, "Think about a container as a piece of used chewing gum. You can then stick the genes and the metabolic molecules directly onto the surface of the gum as long as these molecules are also sticky – or hydrophobic." The team's sticky genes are not made out of DNA or RNA, but rather lipophilic, peptide nucleic acid or PNA. The 'chewing gum' is an aggregate mainly of simple carboxyl acids and the metabolic molecules are amino-pinacol photosensitizes, which can capture light energy, he said.

Liaohai Chen a partner from Argonne National Laboratory said about the coupling, "We recently discovered that the gene molecules actually can be an integral part of the metabolism, if they are used as electron donors and charge transfer devices. Since the gene's charge-transfer properties depend on its sequence, we can directly 'encode' the metabolic efficiency into the genes. Some sequences make for a poor metabolism and others make for good metabolism efficiency."

The team has the simplest and so far the only complete design of a small, living, aggregate, million times smaller than a typical bacterium. It is a living system designed from scratch and even though the pieces work separately, the team stresses that they still have a big challenge ahead because the pieces have to be integrated experimentally. "We have all the pieces, and we have demonstrated that our metabolism can produce the container molecules," said Argonne's Chen.

Applications of Living Technology

John McCaskill at University of Bochum in Germany is the leader of a large European information technology project, of which Los Alamos and Argonne is also a part. The

focus of this project is to program molecular systems that don't understand computer languages. McCaskill said, "Evolution is already a key technology in both public and private sectors for generating molecular functionality. We now also have the technology in hand to use computerized microfluidic to do systems chemistry evolution and bridge the gap to protocells. Start up companies like ProtoLife will be pursuing commercial advantages of this technology. The starting points for the physical system will be Rasmussen's integration scheme, linking in world leaders in component chemistry. The initial target will be a hybrid programmable life-form, with twin evolved environment and chemicals", McCaskill said.

Rasmussen continued, "When you combine self-replicating materials with an ability to program their underlying chemistry to conduct useful tasks, you should be able to grow such micro machines as biosensors, self-repairing ship coatings, systems to sequester carbon dioxide, digest toxins, or bind radionuclides to the soil matrix and more."

"Think about a scratch in your skin and compare that with e.g. a malfunctioning component in a computer." "The skin heals itself while the computer has to be fixed by somebody else. Technology based on the principles of life will become possible once we understand how to make minimal self-replicating materials."

Rasmussen stressed that we cannot do this today "but the science we're doing now is the last obstacle to make a living technology possible. This has incredible mission applications for the Laboratory and industry sees this as an emerging trillion-dollar enterprise."